Applied Energy 115 (2014) 384–393

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Using fuzzy logic to model the behavior of residential electrical utility customers

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HIGHLIGHTS

- Fuzzy logic to model residential user behavior.
- Detailed characterization of activation profiles for appliances.
- Base for the simulation of demand-side management strategies.

ARTICLE INFO

Article history:
Received 10 June 2013
Received in revised form 6 November 2013
Accepted 11 November 2013
Available online 4 December 2013

Keywords:
Fuzzy logic
Load curve
Residential sector

ABSTRACT

Peaks and valleys affecting the efficiency of the power system can be detected by analyzing the load curve. These oscillations are caused by changes in consumer behavior, mainly consumers in the residential sector. This paper presents the use of fuzzy logic systems to model human behavior related to activation of appliances and lighting at home. Based on this model, the hourly activation profile for each appliance can be obtained and, subsequently, the load curve of the residential sector can be calculated. This model aims at contributing to the simulation of strategies for demand-side management.

1. Introduction

A direct consequence of the increased global demand for electricity is the need to use this resource more efficiently. Improving efficiency requires taking measures all along the energy transformation chain, starting with the energy supply, better integration of renewable sources, smaller and decentralized storage systems and suppliers to reduce transportation and distribution losses, and concluding with the smart use of electricity.

Demand-side management must be implemented. In keeping with the definition by Spain's national grid operator (REE), this is defined as "planning and implementing different measures intended to affect how energy is consumed so as to modify the daily consumption profile" [1].

The current behavior for energy demand in Spain can be seen in the load curve (Fig. 1 [2]). The peaks in the graph imply higher energy production, while the valleys offer opportunities to store it.

The aim of controlling demand primarily involves flattening out the load curve by more efficiently generating and distributing electricity. With this objective in mind, various strategies are proposed based on changes in hourly rates, the use of smart meters and appliances, and load shifting [3–5].

A flatter load curve leads to reduced electricity generation costs associated with activating plants during peak hours. Additionally, by reducing the need to cut the supply to the grid from wind turbines during off hours, it also allows for increased reliance on renewable energies. Moreover, the integration of renewable energy would help alleviate Spain's high energy dependence, which in 2011 resulted in the need to import almost 76% [6] of the primary energy consumed in the country.

The users responsible for the demand can be classified into three large groups: industry, services and residential, with the latter group being the main contributor to the formation of peaks and valleys as appliances and lights are turned on and off at different times of the day.

In this paper we propose the use of fuzzy logic systems to simulate the behavior of residential users in terms of energizing appliances and lights in the home. The main advantage obtained from the simulation is that it reduces the risk inherent when designing demand-side management strategies. Simulations can be used to carry out feasibility studies by permitting for "what if" scenarios within the computational models. Different alternatives can be

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http://dx.doi.org/10.1016/j.apenergy.2013.11.030

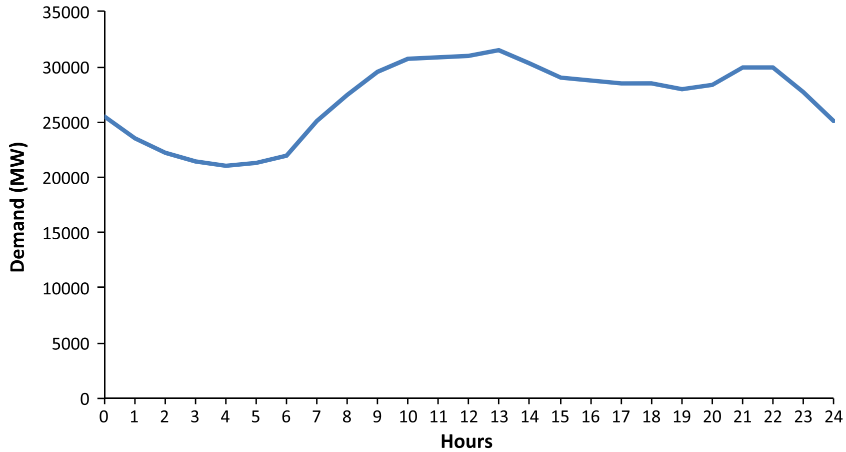

Fig. 1. Energy demand curve on 24 May 2013. Constructed from the data provided by the website of Spain's national grid operator [2].

tested and those yielding the best performance selected. The solutions proposed for the different problems can be analyzed in less time than if the effects of the changes had to be observed in the real system. Furthermore, the experimental conditions (source of randomness, warm-up time, etc.) can be better defined in a simulation, meaning that only those solutions resulting from the same experimental conditions can be compared. Another advantage of simulated experiments is the ease with which the experiment can be paused while the results are analyzed and changes to the parameters are considered. This is useful when trying to make incremental improvements to procedures.

An additional benefit obtained when writing a simulation program is that all of the requirements imposed on the new system must be carefully determined and documented. The process of creating all the logical relationships needed in a simulation should also reveal any problems. This leads to increased knowledge of the system, since information must be compiled from different sources. All of the knowledge gained during the simulation phase will continue to be of great value during the life of the project. The advantages of a simulation can be summarized as follows: it reduces risk by increasing knowledge of how the new system to be built works or of how changes will affect an existing system.

2. State of the art

The methods for determining how to model the load curve or residential demand are classified into two main groups: the Top-Down and the Bottom-Up methods [7,8]. These methods refer to types of inputs used by the two approaches. In Top-Down methods, general information and statistics from large-area studies of electricity consumption are available and used to calculate the consumption in a single dwelling or in a small group of dwellings. In contrast, Bottom-Up methods start with specific consumption data for some dwellings and seek to extrapolate those data to calculate consumption for wider areas such as cities, regions or countries.

Modeling the residential load curve requires taking into account different input types, such as gross domestic product, household economy, appliance types, weather information and dwelling construction properties. A key criterion when deciding which types of input data to use is the accessibility to said data. That is why human behavior, which has a drastic influence on the consumption curve [7], has not generally been considered as an input in the residential load curve models published in the literature.

Grandjean et al. [7] offer a review and analysis of residential load curve models. Notable among these models is the one by Walker and Pokoski [9], which was the first model reviewed that considered human behavior when reconstructing the residential load curve. As the authors note, the complexity involved in acquiring these data forced them to consider just one scenario with a single working individual living in the home. This scenario is then used to generate variations that rely on probability distribution functions to modify the start time of the main activities. They also propose the use of a proclivity function that is constructed based on other published studies. This function is used to calculate the tendency of people to engage in certain activities at a given time of day.

Capasso et al. [10] developed ARGOS, which improved on the Walker and Pokoski model and became a reference point for subsequent models, especially those that encompass the modeling of human behavior. ARGOS simulates the load curve of residential users by considering four household activities: cooking, household chores, leisure and personal hygiene. Each member of the household is characterized using a presence scenario and a tendency to perform each household activity. Some parameters, such as the time of year or whether it is a workday, were not considered in this model, nor were the dwellings' insulation characteristics.

Annex 42 of the International Energy Agency's Energy Conservation in Buildings and Community Systems Programme IEA/ECBCS proposes "The Simulation of Building-Integrated Fuel Cell and Other Cogeneration Systems (FC+COGEN-SIM)" [11]. One of its objectives is the generation of load profiles for residential users in Canada using a bottom-up approach. Information on appliances, consumption and occupation patterns are used as the input data, which is adjusted using heterogeneous data sources, including the database on electricity usage from Canada's Office of Energy Efficiency, Natural Resources. The main constraint on the use of this method, according to the authors, is the availability of input data [12].

The model in Richardson et al. [13] used data from studies that contain detailed logs on household activities for 21,000 dwellings. These logs were used to create presence and activity profiles every ten minutes. They also took into account data on appliances, such as penetration rates, annual consumption and load factor, as well as weather and seasonal information, statistical demographic data and total load curves for 22 dwellings. With these data the model can calculate the demand curve for a dwelling based on the number of household members, the day of the week and the month of the year.

The model in Train et al. [14] also relies on study data. Specifically, it uses total load curves and end-use curves for the monitored appliances of 800 users, socioeconomic data such as